Title

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^{142}Nd(^{18}O,^{16}O)^{144}Nd Reaction and its contrast to ^{144}Nd(^{12}C,^{14}C) ^{142}Nd Reaction*

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Abstract

An investigation is made of the ^{142}Nd(^{18}O,^{16}O)^{144}Nd reaction and compared with the inverse-type reaction ^{144}Nd(^{12}C,^{14}C)^{142}Nd.

[NUCLEAR REACTIONS ^{142}N(^{18}O,^{16}O), E = 98 MeV;
Measured σ (θ), DWBA analysis.]

Investigation of two-nucleon transfer reactions induced by light-ions, such as (p,t) and (t,p) reactions, has been recognized as a powerful tool in obtaining information concerning the correlation of the nucleon pairs which is revealed, for example, in the excitation of the pairing vibrational states[1]. Similar information on this correlation can be obtained by carrying out two-nucleon transfer reactions induced by heavy-ions. In the present article the ^{142}Nd(^{18}O, ^{16}O)^{144}Nd reaction leading to the quadrupole-pairing vibrational states of removal (RQP) and addition (AQP) types is investigated, and compared with the inverse-type reaction ^{144}Nd(^{12}C, ^{14}C)^{142}Nd which we reported earlier[2].

A characteristic feature of a RQP (AQP) state is that it is excited strongly (weakly) by a pickup reaction, like (p,t), while the situation is reversed for a stripping reaction. In fact, previous (p,t) work[3,4] showed that the transitions to the RQP-type 2^+ states were strong and were of direct (one-step) nature. On the other hand the transition to the AQP-type 2^+ state was much weaker and also had an anomalous angular distribution. A marked example of such an anomalous angular distribution was that of the ^{144}Nd(p,t)^{142}Nd(2_1^+) transition[5], which could be fitted well by CCBA, but not by DWBA. A very similar situation was encountered in the ^{144}Nd(^{12}C, ^{14}C)^{142}Nd(2_1^+) reaction[2].

It is interesting to perform the inverse stripping reaction, but to carry out a (t,p) reaction, particularly at high energy, is difficult. On the other hand, it is quite feasible to carry out two-nucleon stripping reactions induced by heavy-ions, and it is for this reason that the present (^{18}O, ^{16}O) experiment was undertaken. A similar comparison between pickup and stripping reactions on Sn targets was reported recently, showing that the interference between the direct and indirect transitions to the final 2_1^+ state was constructive (destructive) for pickup (stripping) reactions[6].

The present experiment was performed by using a 98 MeV ^{18}0 beam from the Berkeley 88-inch cyclotron. Reaction products were detected with the QSD-type magnetic spectrometer[7]. Particle identification and energies of the reaction products were obtained by a combination of magnetic rigidity, a double dE/dx measurement and the time-of-fight method[8]. Fig. 1 shows an energy spectrum of the ^{16}0 ions from the ^{142}Nd(^{18}0, ^{16}0)^{144}Nd reaction. A 350 μg/cm^2 self-supporting, isotopically-pure metallic ^{142}Nd target gave a resolution of 250 KeV.

The differential cross sections for the ^{142}Nd(^{18}0,^{16}0) reaction leading to the ground state (0_g^+) and the first excited 0.69 MeV (2_1^+) state of ^{144}Nd are shown in Fig. 2. As is seen, both the 0_g^+ and the 2_1^+ states are strongly populated, and both display bell-shaped angular distributions characteristic of one-step transitions. The peak of the cross sections occurs at $\theta_{cm} \approx 50°$.

The theoretical analysis was performed by using an EFR-microscopic version[9] of the DWBA code SATURN-MARS-1[10]. The wave functions used for ^{142}Nd and ^{144}Nd were constructed in the same manner as in Refs. 2 and 11. Both the pairing-type (of monopole and quadrupole nature) and the particle-hole-type (of quadrupole nature) interactions were used and thus the wave function for the two extra-nucleons in ^{144}Nd had rather complicated configuration mixing. For the two extra-nucleons in ^{18}0, we used the configuration mixing described by Bayman[12]. The radial part of the wave functions for the single neutrons was constructed as an eigensolution of a Woods-Saxon potential with r_o = 1.25 fm and a = 0.65 fm, combined with the well known half-the-separation-energy procedure. By first expanding these radial wave functions in terms of oscillator functions, then transforming by the Moskinsky procedure to the relative and center-of-mass coordinates, and finally integrating over relative coordinates, we obtain the form factor expressed in terms of the wave functions that describe the motion of the center of the mass of the two nucleons in ^{144}Nd and ^{18}O. The remaining construction of the form factor then follows the procedure described in detail in ref. 10. (A very similar construction of the form factor for two-nucleon transfer reaction was also made by Takemasa[13].)

In the course of taking the reaction data, the elastic scattering of ^{18}O by ^{142}Nd was also measured and the differential cross section is shown in Fig. 3, together with the fit with the optical parameters V = 100 MeV, W = 24.24 Mev, r_o = 1.25 fm, a = 0.502 fm, r_I = 1.20 fm and a_I = 0.67 fm. The fit is very good.

Using the optical parameters as given in the preceding paragraph, and the form factor obtained as described above, EFR-DWBA calculations were performed for both 0_g^+ and 2_1^+ final states, with the results shown as solid lines in Fig. 2. The fit is very good, including the correct prediction of the relative magnitudes of the cross sections to the two final states. We have also carried out EFR-CCBA calculations with results that differed only very slightly from that of EFR-DWBA calculations. In plotting the theoretical cross sections in Fig. 2, an overall normalization factor $N \equiv \sigma_{exp}/\sigma_{th}$ which is as large as 38 had to be used, as it was the case in many two-nucleon transfer reactions[14].

In conclusion we have shown that the ^{142}Nd(^{18}O, ^{16}O)^{144}Nd reaction contrasts distinctly with the ^{144}Nd(^{12}C, ^{14}C)^{144}Nd reaction, indicating the validity of introducing the concept of RQP and/or AQP states. It should be remarked that the 2^+ state at 3.5 MeV was excited very weakly in the present experiment, as is seen in Fig. 1, while it was excited very strongly in the (p,t) reaction[3,4]. Without carrying out any detailed theoretical analysis, this state may very well be identified as a RQP state.

We finally reemphasize the fact that in our present analysis CCBA and DWBA results were practically the same, indicating that in exciting the 2_1^+ state the direct $0^+ \rightarrow 2_1^+$ transition was strong compared to the indirect $0^+ \rightarrow 0_g^+ \rightarrow 2_1^+$ transition. In the (^{12}C,^{14}C) reaction[2] these two amplitudes were comparable; they were comparable in both pickup and stripping reactions from Sn isotopes[6]. The reason for contrast between the pickup and stripping reactions with Nd nuclei and those with Sn nuclei, is that the Nd had neutron numbers very close to the magic N = 82, while those in Sn did not. Therefore, in our case the RQP and/or AQP nature of excitations were preserved with higher purity than with the Sn isotopes.

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FOOTNOTES AND REFERENCES

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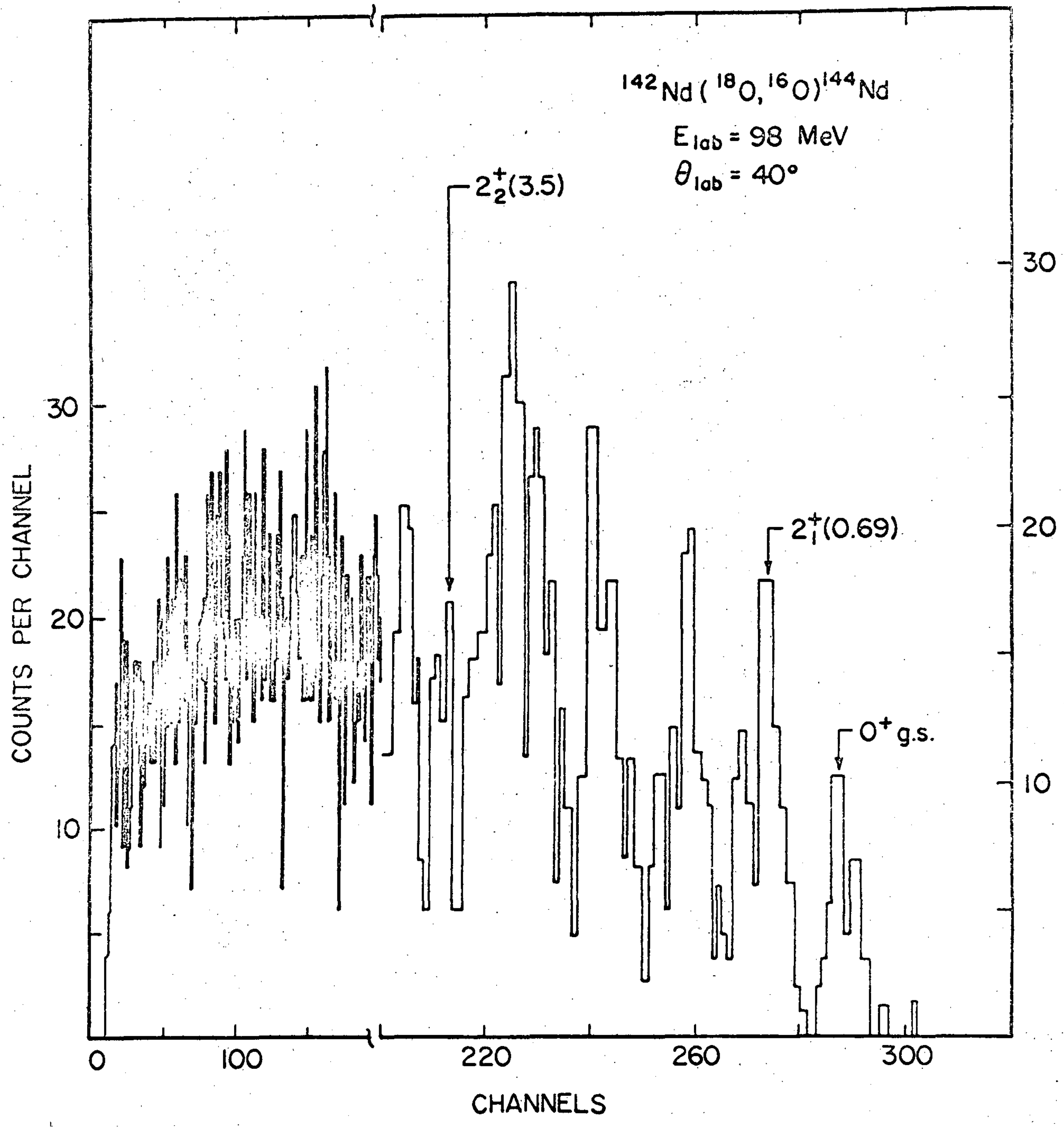
FIGURE CAPTIONS

Fig. 1. Typical spectrum of the ^{142}Nd(^{18}O,^{16}O)^{144}Nd reaction. Note the change of scale for channel numbers beyond 200.

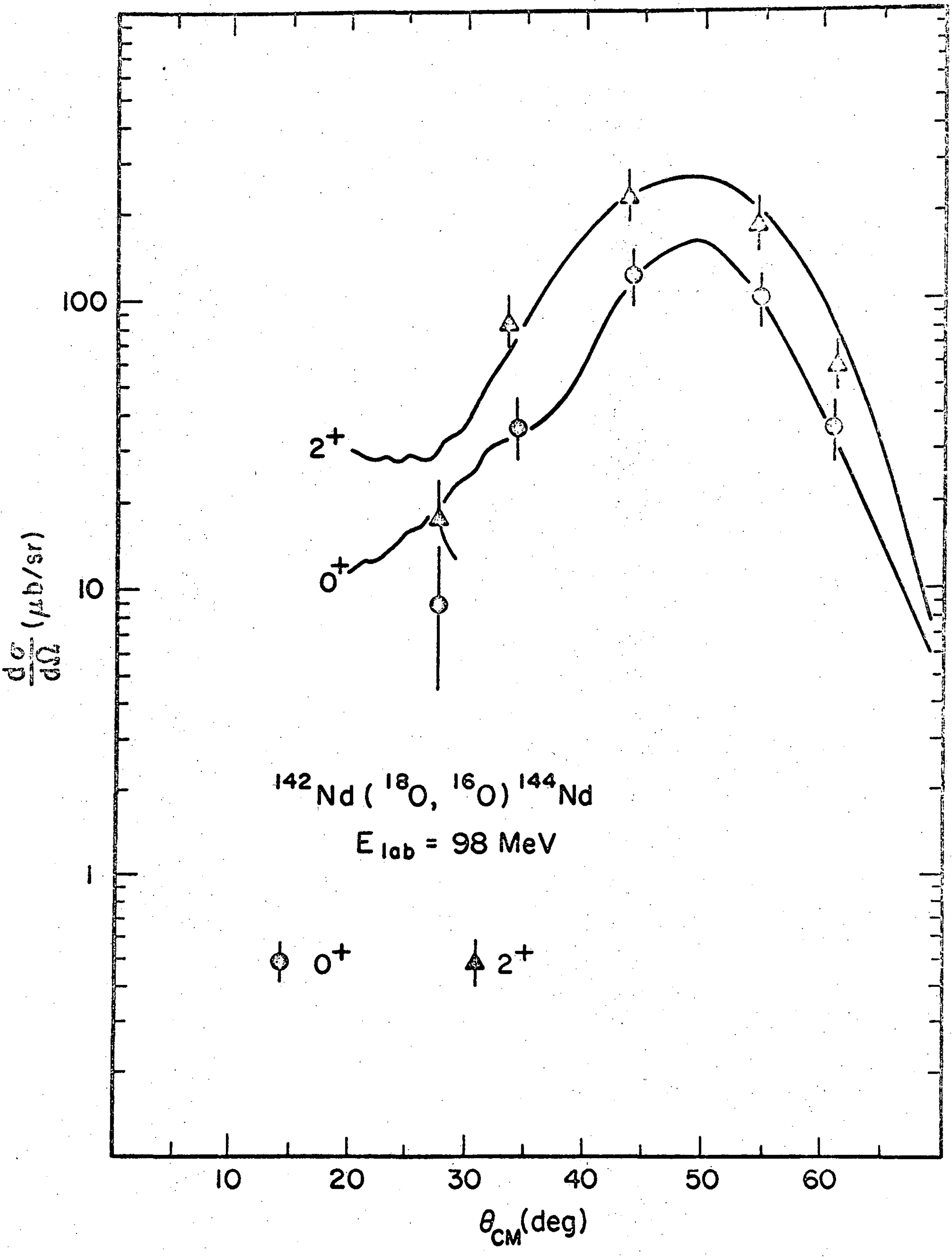
Fig. 2. Differential cross section of the ^{142}Nd(^{18}O,^{16}O)^{144}Nd reaction. The solid lines are theoretical cross sections obtained with EFR-DWBA calculations.

Fig. 3. Differential cross section of the elastic scattering between ^{18}O and ^{142}Nd. The incident ^{18}O lab energy is 98 MeV. The solid line is the theoretical cross section obtained with the optical parameters given in the text.



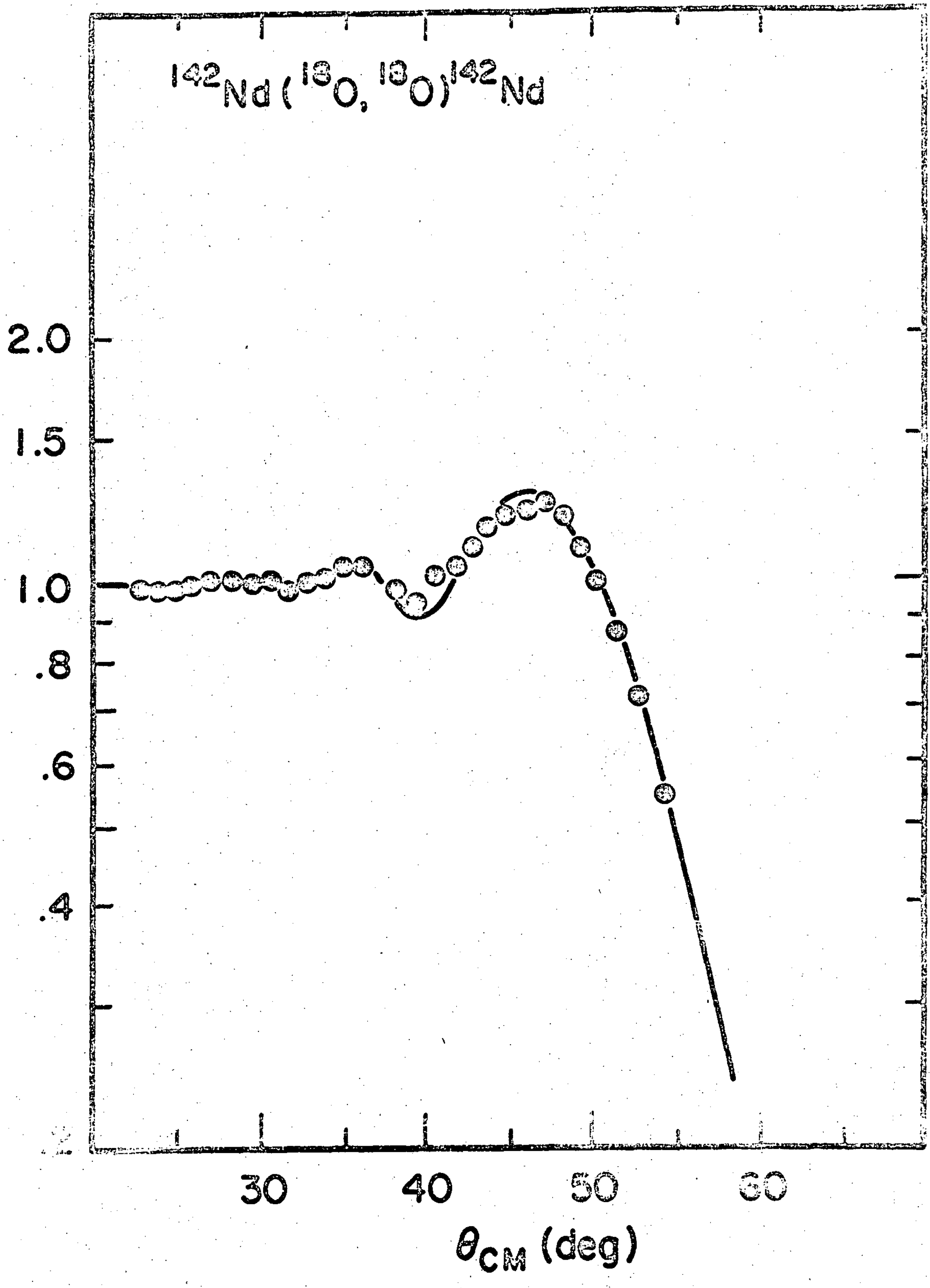
^{142}Nd (^{18}O, ^{16}O)^{144}Nd
E_{lab} = 98 MeV
θ_{lab} = 40°
2_2^+(3.5)
2_1^+(0.69)
0^+ g.s.
COUNTS PER CHANNEL
CHANNELS
0
100
220
260
300
10
20
30

Fig. 1



$\frac{d\sigma}{d\Omega}$ (μb/sr)
100
10
1
^{142}Nd (^{18}O, ^{16}O) ^{144}Nd
E lab = 98 MeV
2+
0+
0+
2+
10
20
30
40
50
60
θ_{CM}(deg)

Fig. 2



^{142}Nd(^{18}O, ^{18}O)^{142}Nd
2.0
1.5
1.0
.8
.6
.4
.2
$\sigma_{el}/\sigma_{Ruth}$
30
40
50
60
θ_{CM} (deg)

Fig. 3

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